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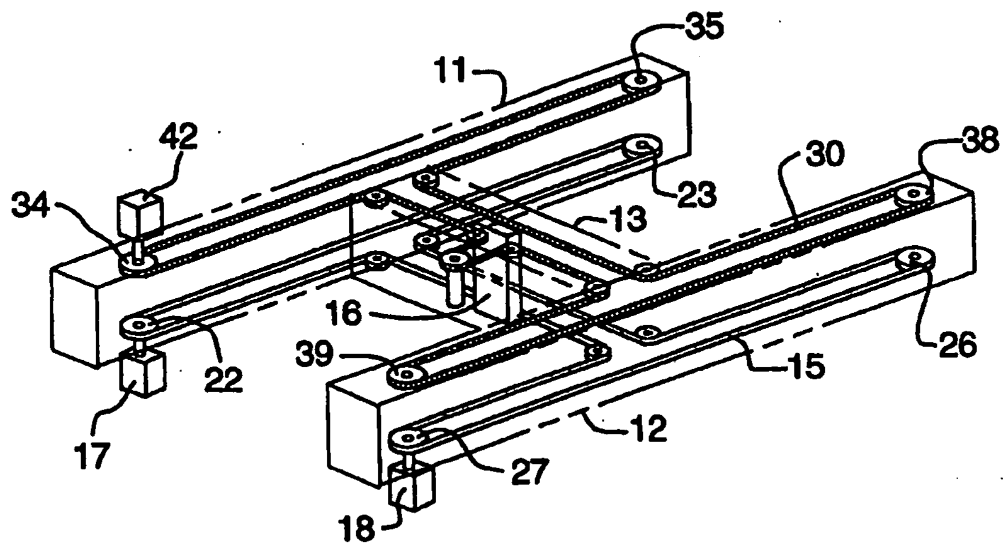
(54) Title: MULTI-AXIS ROBOTS



(57) Abstract

Various related belt configurations are used to provide an additional axis of motion to a movable tool plate. At least one tool plate (16) is movable in at least one axis of motion by virtue of attachment to a belt (15), the belt being driven by at least one motor (17). There is at least one additional belt (30) and at least one additional motor (42) to drive the additional belt(s), the additional belt(s) being routed to the tool plate(s) and being selectively operable by the additional motor(s) to produce motion of the additional belt(s) relative to the tool plate(s). The belt motion may be connected in any desired fashion to produce motion of a tool (31) or tools relative to the tool plate(s).

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MULTI-AXIS ROBOTS

TECHNICAL FIELD

This invention relates to industrial robotics, and in particular to providing an additional axis of movement at a movable tool plate. As one example, the invention can be used to add z or theta movement to x-y movement of a tool plate. Other examples will be described herein.

BACKGROUND ART

Until recently, although various designs for positioning apparatus using belts (or chains or cables or the like) have been known, the available belts have been too susceptible to being stretched to be used practically, particularly in applications requiring high precision. However, belt technology has reached the state where essentially non-stretchable belts are now economical and viable. Repeatable motion is therefore achievable with belts.

Many two-axis belt or cable arrangements are known, but there remains a need for belt configurations which can be used to provide reliable and economical movement of tooling relative to a movable tool plate, without adding substantial mass to the tool plate itself or to other moving components.

DISCLOSURE OF INVENTION

In the invention, various related belt configurations are used to provide an additional axis of motion to a movable tool plate.

In one configuration, for example, a second belt is added to a single-belt, two-axis configuration. The second belt provides the third axis. The first belt, driven by two motors, provides x-y motion of the tool plate, while the second belt can be operated to move relative to the tool plate, such that the relative motion can be used to provide theta, z-axis or other movement of the tooling relative to the tool plate.

In the invention as broadly conceived, there is at least one tool plate movable in at least one axis of motion by virtue of attachment to a belt, the belt being driven by at least one motor. The invention provides at least one additional belt and at least one additional motor to drive the additional belt(s), the additional belt(s) being routed to the tool plate(s) and being

selectively operable by the additional motor(s) to produce motion of the additional belt(s) relative to the tool plate(s). The belt motion may be connected in any desired fashion to produce motion of a tool or tools relative to the tool plate(s).

The invention essentially permits almost any desired combination of movements to be provided from a "toolkit" of standard components, namely the rails, beams, slides, belts, pulleys and motors, etc.. This flexibility makes it possible to build inexpensive, high performance, high speed robots, with a wide variety of configurations to meet a wide variety of needs.

BRIEF DESCRIPTION OF DRAWINGS

In order that the invention may be more clearly understood, the preferred embodiment thereof will now be described in detail by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic perspective view of a two-belt, three-axis H-shaped robot;

Fig. 2 is a cross-section showing just the belt which moves the tool plate, in this case the lower belt;

Fig. 3 is a cross-section showing just the upper belt, which provides a third axis of motion;

Fig. 4 is a schematic perspective view similar to Fig. 1, but showing the upper belt optionally following a "T" shape instead of following the full "H" shape;

Fig. 5 is a schematic cross-section similar to Fig. 3, but showing the upper belt configured as in Fig. 4;

Fig. 6 is a schematic cross-section in which the lower belt also follows only a T-shape (thus giving up one axis of motion, as will be explained);

Fig. 7 is a schematic cross-section corresponding to Fig. 6, but dispensing with the second rail;

Fig. 8 is a schematic perspective view illustrating how a second belt added to the configurations of Figs. 6 or 7 can add a second axis of motion;

Fig. 9 is a schematic perspective similar to Fig. 1, but showing two tool plates driven by the lower belt, one on each side of the beam, the two platforms thus moving in concert

with each other (in opposite directions along the beam), and the third axis operations being in concert with each other;

Fig. 10 is a schematic cross-section showing the lower belt of Fig. 9;

Fig. 11 is a schematic perspective similar to Fig. 9, but showing the addition of a third belt to provide independent operation of the third axis at the two tool plates;

Fig. 12 is a cross-section showing just the lower belt of Fig. 11, which provides concerted movement of the two tool plates;

Fig. 13 is a cross-section showing just the middle belt of Fig. 11, which provides a third axis of motion at one of the tool plates;

Fig. 14 is a cross-section showing just the upper belt of Fig. 11, which provides a third axis of motion at one tool plate, independent from the third axis of motion at the other tool plate;

Fig. 15 is a schematic perspective view, showing a configuration with two independently movable beams and tool plates; and

Fig. 16 is a schematic perspective view similar to Fig. 15, showing two toolplates on each beam.

BEST MODE FOR CARRYING OUT THE INVENTION

Figs. 1-3 illustrate the basic "H" shape of the primary embodiment of the invention. The robot has parallel first and second stationary rails **11** and **12**, which are held firmly in place on any suitably rigid base (not shown). A movable beam **13** is mounted between slides **14** which are slidably mounted on facing sides of the rails.

Fig. 2 shows a first belt **15** (in this case the lower belt) which is routed around various pulleys so as to achieve the desired x-y movement of a tool plate **16**, by operation of motors **17** and **18**, as will be explained. The basic routing of the first belt is as follows: from the tool plate **16**, around a first lower pulley **21** on a slide, thence around a second lower pulley **22** at one end of the first rail, thence around a third lower pulley **23** at the other end of the first rail, thence around a fourth lower pulley **24** on the slide, thence along the movable beam and around a fifth lower pulley **25** mounted on the second slide, thence along the second rail and around a sixth lower pulley **26** at one end of the rail, thence along the second rail and around a seventh

lower pulley **27** at the other end of the rail, thence around an eighth lower pulley **28** mounted on the second slide, and thence back to the tool plate **16**.

The basic two-axis motion of the tool plate is provided by the operation of motors **17** and **18** to drive any two pulleys on opposite rails, such as pulleys **22** and **27** for example. Alternatively, it is possible to position the driving means anywhere along the path of the belt so long as the two drive means are separated by the movable rail; in other words, the drive means must be on different stationary rails.

As can be readily seen from brief consideration of Fig. 2, for example, coordinated operation of the two motors will produce any desired x-y motion of the tool plate. For example, clockwise rotation of one motor and counterclockwise rotation of the other motor at the same rpm will produce x-axis motion of the tool plate (i.e. motion parallel to the rails). Rotation of both motors in the same direction at the same rpm will produce y-axis motion (i.e. along the beam). Rotation of just one of the motors will produce 45 degree motion. By varying the rpms and directions of rotation, any x-y motion can be achieved.

Fig. 3 shows the second (in this case upper) belt **30**, which is routed around a tool drive **31** (shown schematically only), thence around a first upper pulley **32**, thence around a second upper pulley **33** on a slide, thence around a third upper pulley **34** at one end of the first rail, thence around a fourth upper pulley **35** at the other end of the first rail, thence around a fifth upper pulley **36** on the slide, thence along the movable beam and around a sixth upper pulley **37** mounted on the second slide, thence along the second rail and around a seventh upper pulley **38** at one end of the rail, thence along the second rail and around an eighth upper pulley **39** at the other end of the rail, thence around a ninth upper pulley **40** mounted on the second slide, and thence around a tenth upper pulley **41** and back to itself at the tool drive **31**. A motor **42** drives one of the large pulleys, such as the third upper pulley **34**, to drive the upper belt.

Examination of Figs. 1 and 3 shows that movement of the upper belt **30** in coordination with the movement of the tool plate can be used to produce a third axis of motion at the tool plate. The motor **42** can be operated so that there is no movement of the belt relative to the tool plate as the tool plate moves, or relative motion can be created so as to drive a tool in a third axis. The axis shown by tool drive **31** is theta, i.e. rotation about the central axis of the tool drive, but it should be readily apparent that the rotation can be converted to z-motion by any conventional means, for example by rotating a ballscrew or the like on a threaded rod, to produce

z-axis movement of the threaded rod, which could in turn be connected to drive a tool mount up or down.

Similarly, it should be apparent that motion of the belt relative to the tool plate could be used directly if desired for any particular application, for example to slide a tool or tool mount laterally along the tool plate, that tool or tool mount being connected to the belt.

Fig. 4 is a schematic perspective view similar to Fig. 1, but showing the upper belt optionally following a "T" shape instead of following the full "H" shape. Fig. 5 is a corresponding plan view. Thus instead of the rail **12** being provided with pulleys **38** and **39**, and the beam **13** being provided with pulleys **37** and **40**, the beam is provided only with pulley **45** (or several smaller pulleys could be used). This arrangement is less desirable than the Fig. 1 arrangement, due to the potential for skewing of the beam, but is nevertheless certainly possible. The Fig. 1 arrangement provides better symmetry of forces.

Fig. 6 is a schematic cross-section in which the lower belt also follows only a T-shape. This produces only one axis of motion, as can be seen from consideration of Fig. 6. If the beam is prevented from moving, then movement of the belt **15** will produce y-axis movement of the tool plate **16**, i.e. along the beam. If the y-axis movement is prevented, i.e. if the tool plate is secured to the beam, then movement of the belt will produce x-axis movement of the tool plate, i.e. the beam will move. If neither movement is prevented, then the tool plate movement will not be properly controlled or constrained, in the absence of additional means.

Fig. 7 is a schematic cross-section corresponding to Fig. 6, but dispensing with the second rail **12**. In Fig. 6, the second rail serves no operational function; it merely provides support for the beam. In Fig. 7, the beam is cantilevered.

Fig. 8 is a schematic perspective view illustrating how a second belt **48** (essentially corresponding to belt **30** in the earlier drawings), driven by the motor **42**, can be added to the configurations of Figs. 6 or 7 to add a second axis of motion. The belt is attached to the slide **14**, and is routed around pulleys **34** and **35**. This routing produces movement of the slide along the rail when the motor **42** is operated. As in the earlier examples, coordinated operation of the motors **42** and **17** will produce controlled x-y motion of the tool plate **16**.

Fig. 9 is a schematic perspective similar to Fig. 1, but showing two tool plates **16** and **16'** connected to and driven by the lower belt, one on each side of the beam **13**, the two platforms thus moving in concert with each other along the beam (albeit in opposite directions),

and the third axis operations also being in concert with each other, for example operating tool drives **31** and **31'**. Fig. 10 is a schematic cross-section showing the upper belt **30** of Fig. 9.

Fig. 11 is a schematic perspective similar to Fig. 9, but showing the addition of a third belt **50**, driven by motor **51**, to provide independent operation of the third axes at the two tool plates. Figs. 12-14 are cross-sections showing the lower, middle and upper belts **15**, **30**, and **50** respectively. As can be readily seen, belts **30** and **50** provide independent control of the tool drives **31** and **31'** respectively, while the lower belt controls movement of the platforms **16** and **16'**.

In this configuration, as in Fig. 9, the tool plates move in concert. However, Fig. 11 illustrates an important principle of the invention, which is that additional belts can be added whenever it is desired to obtain additional axes of motion or independence of motion. Thus, through appropriate routing and driving of additional belts, in a similar manner to than shown in Fig. 11, it would be readily possible, for example, to achieve independent rather than concerted movement of the tool plates; independent operation of tools on the tool plates; multiple independently-driven tools on the same tool plate or different tool plates; and so on. Obviously, at a certain point there becomes an undesirable number of belts and an impractical degree of resulting complexity, but in principle there is nothing preventing the invention from being implemented with ten or more belts, if desired, however unlikely that may be in practice.

Fig. 15 shows that not only are such variations possible with a single beam, but also with two (or more) independently operable beams **13** and **13'**. The lower belt **15** would move tool plate **16** via two motors as in the earlier-described embodiments, and the upper belt **60** would similarly move the tool plate **61** via two other motors (not shown). Fig. 16 additionally shows that each beam could be provided with two tool plates, similar to Fig. 9. Independent operation of the tool plates **16**, **16'**, **61** and **61'**, and/or of the individual tools, and so on, could be achieved as explained in conjunction with the above description of Fig. 11, simply by adding more belts and motors in similar fashion.

INDUSTRIAL APPLICABILITY

The invention provides tremendous flexibility in adding additional functionality to a robotic system, without adding any significant moving mass. The motors remain stationary, and thus the tools can be moved around without also having to move the mass of the motors. The

systems can be assembled from essentially a standard kit of parts, including various rails, slides, pulleys, belts, motors, etc.. Systems can thus be designed and assembled very quickly and efficiently, to meet a wide variety of needs.

__CLAIMS:__

1. A multi-axis robot comprising at least one tool plate (16) movable in at least one axis of motion by virtue of attachment to a belt (15), said belt being driven by at least one motor (17), characterized by at least one additional belt (30) and at least one additional motor (42) driving said at least one additional belt, said at least one additional belt being routed to said tool plate and being selectively operable by said at least one additional motor to produce motion of said at least one additional belt relative to said tool plate in coordination with any movement of said tool plate, which belt motion may be connected to produce motion of a tool relative to said tool plate.

2. A multi-axis robot as in claim 1, further characterized by first and second spaced-apart parallel rails (11, 12) and a beam (13) perpendicular to said rails, slidably mounted therebetween, where at least one of said at least one tool plates is slidably mounted on said beam, said belt (15) being routed around pulleys (21-28) generally in an H-shape following said rails and said beam, with a first motor (17) on one rail and a second motor (18) on the other rail both connected to drive said belt, whereby coordinated operation of said first and second motors produces x-y motion of said tool plate, where the x direction is the direction of the rails, and the y direction is the direction of the beam.

3. A multi-axis robot as in claim 2, further characterized by said at least one additional belt (30) being a belt routed around pulleys (32-41) along at least one of said rails and at least the length of said beam, via said tool plate, said at least one additional motor (42) being on said rail, connected to drive said belt.

4. A multi-axis robot as in claim 1, further characterized by at least one rail (11) and a beam (13) extending perpendicularly to said rail, slidably mounted thereon, said belt (15) being routed around pulleys (21-24, 46) generally in an T-shape following said rail and said beam, with a first motor (17) on said rail being connected to drive said belt and said second motor (42) on said rail being connected to drive a second belt, said second belt being routed around suitable pulleys (34, 35) the operating length of said rail and being connected to said beam, whereby said

beam constitutes said tool plate, moving in the x-direction only, and said second belt produces y-direction of a secondary tool plate along the beam, whereby coordinated operation of said first and second motors produces x-y motion of said secondary tool plate, where the x direction is the direction of the rails, and the y direction is the direction of the beam.

5. A multi-axis robot as in claim 1, where there are at least two said tool plates (16, 16') movable in at least one axis of motion by virtue of attachment to said belt (15).

6. A multi-axis robot as in claim 5, where there are at least three belts, namely one belt (15) routed to produce x-y motion of said tool plates, one belt (30) routed to provide another axis of motion to one of said tool plates (16), and one belt (50) routed to provide another axis of motion to the other of said tool plates (16').

7. A multi-axis robot as in claim 1, further characterized by first and second spaced-apart parallel rails (11, 12) and at least two beams (13, 13') perpendicular to said rails, slidably mounted therebetween, where at least one of said at least one tool plates is slidably mounted on each said beam, where first and second belts (15, 60) are routed around pulleys (21-28) generally in an H-shape following said rails and each following a respective one of said beams, with a first motor (17) on one rail and a second motor (18) on the other rail both connected to drive said first belt (15), and a third motor on one rail and a fourth motor on the other rail both connected to drive said second belt (60), whereby coordinated operation of said motors produces x motion of said beams and x-y motion of said tool plates, where the x direction is the direction of the rails, and the y direction is the direction of the beams.

8. A multi-axis robot as in claim 1, further characterized by multiple said additional belts routed to at least one of said tool plates, selectively operable by said motors to produce multiple motions at said at least one of said tool plates.

9. A multi-axis robot as in claim 1, further characterized by multiple said additional belts routed to multiple tool plates, selectively operable by said motors to produce multiple motions at said multiple tool plates.

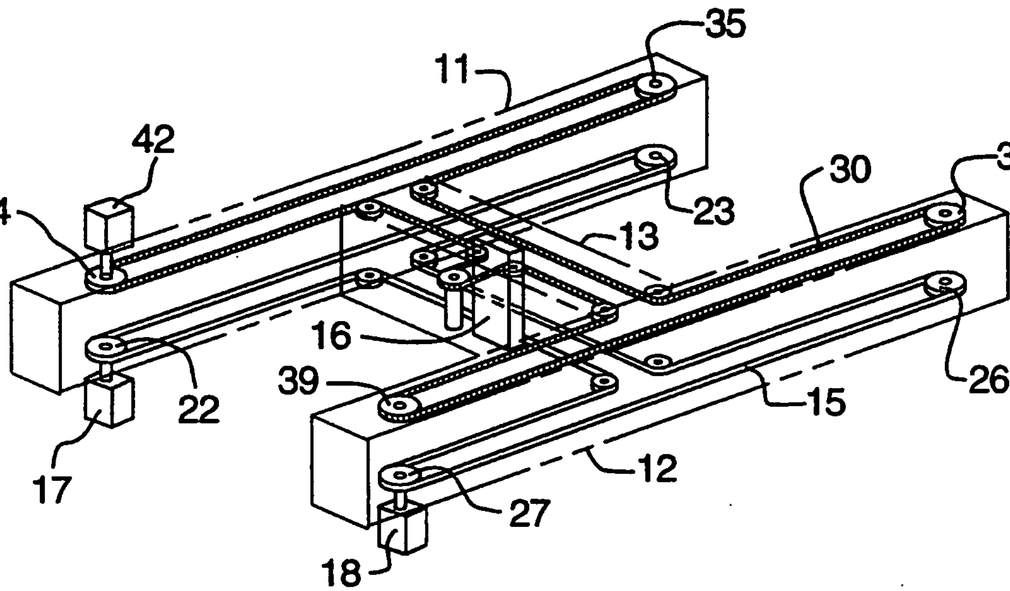

FIG.1

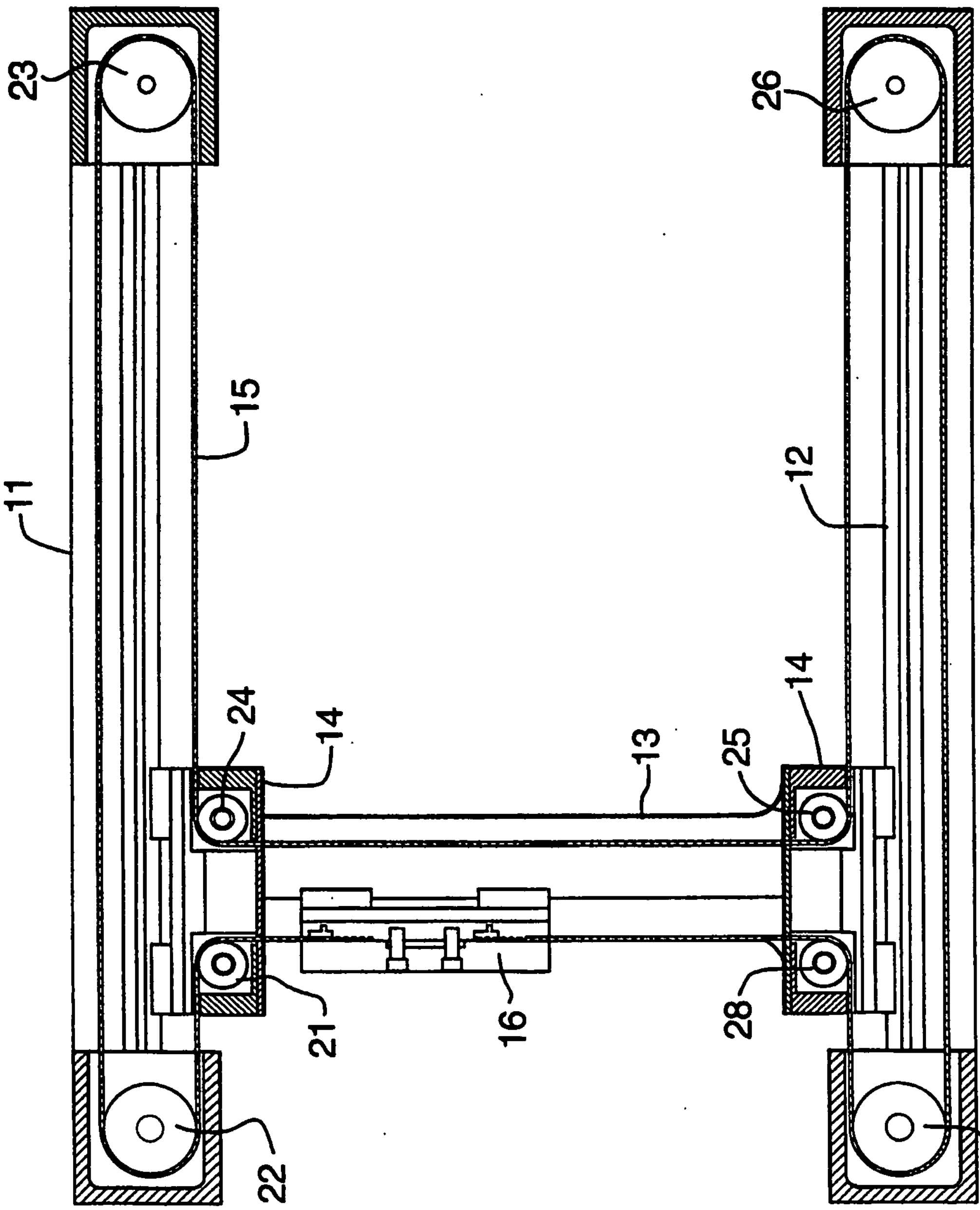

FIG.2

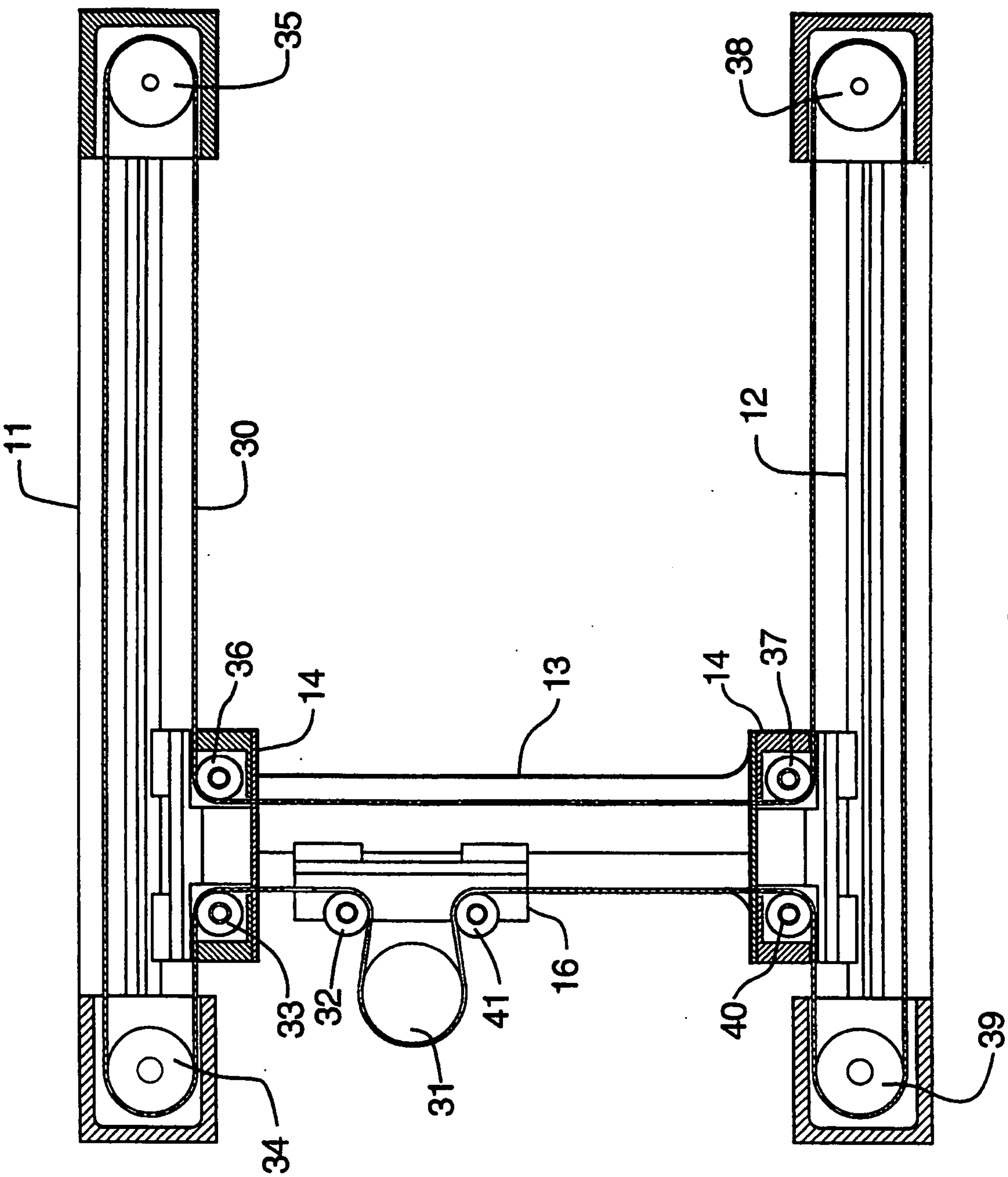

FIG.3

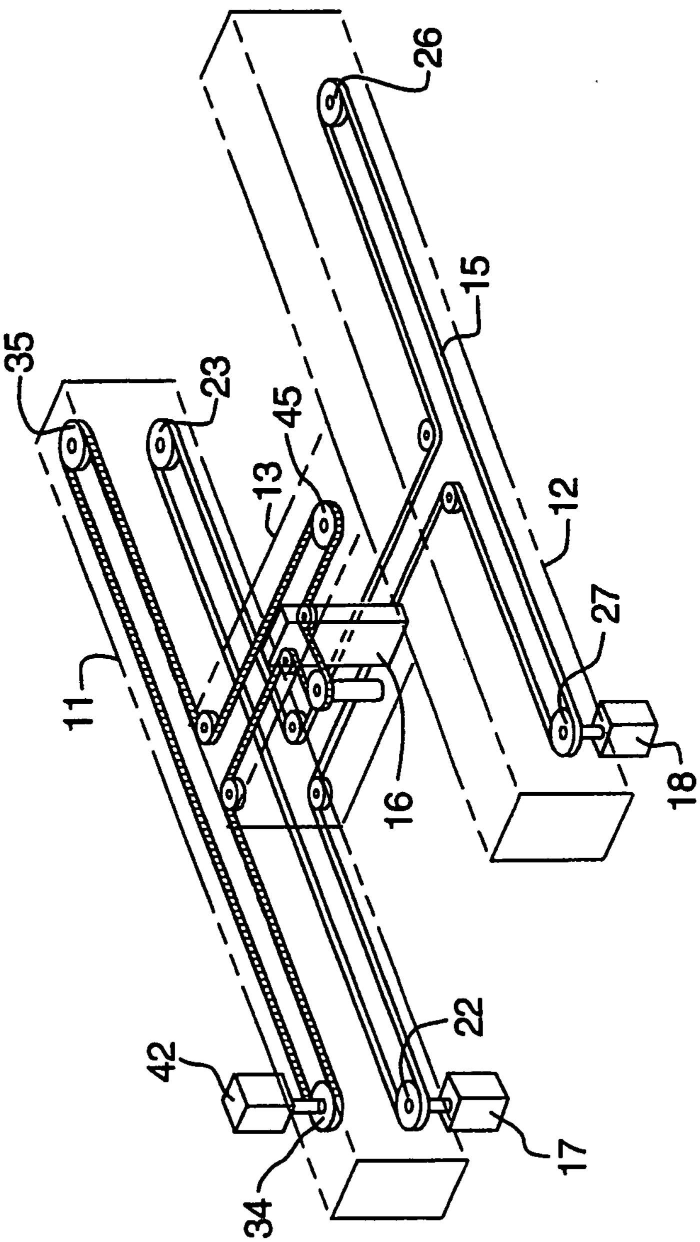

FIG.4

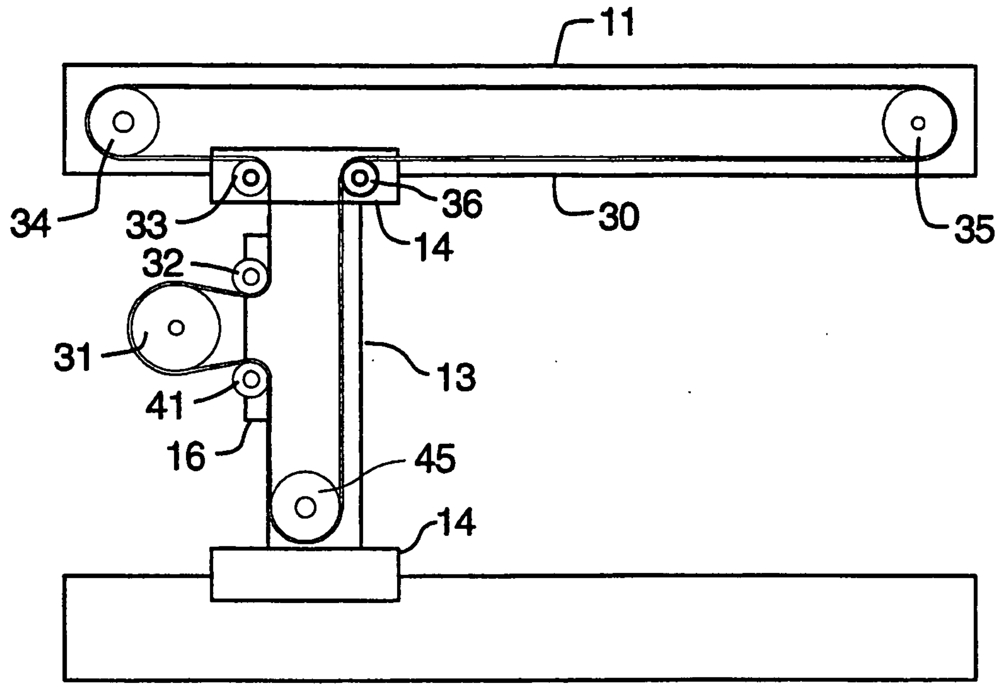
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FIG.5

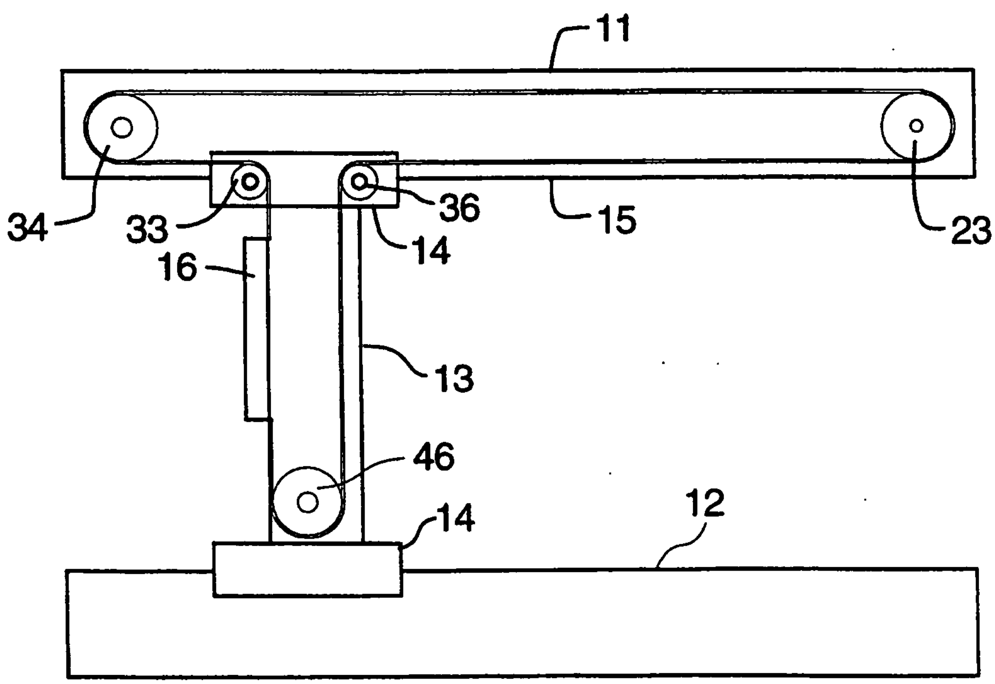
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FIG.6

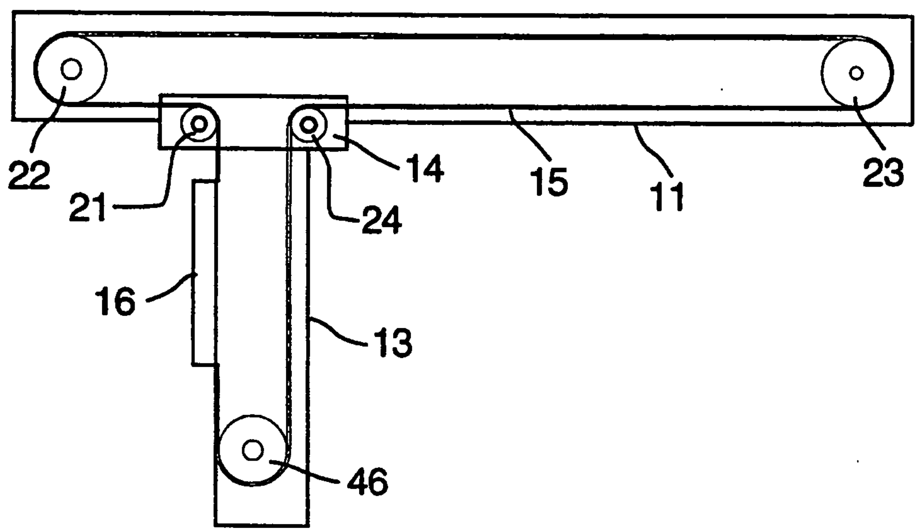

FIG.7

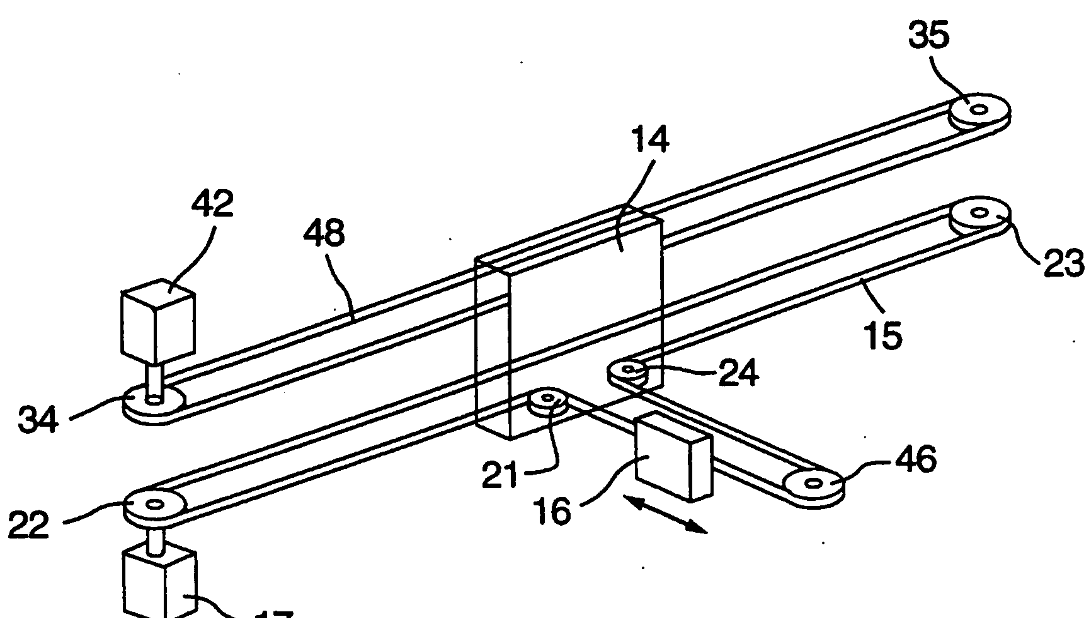

FIG.8

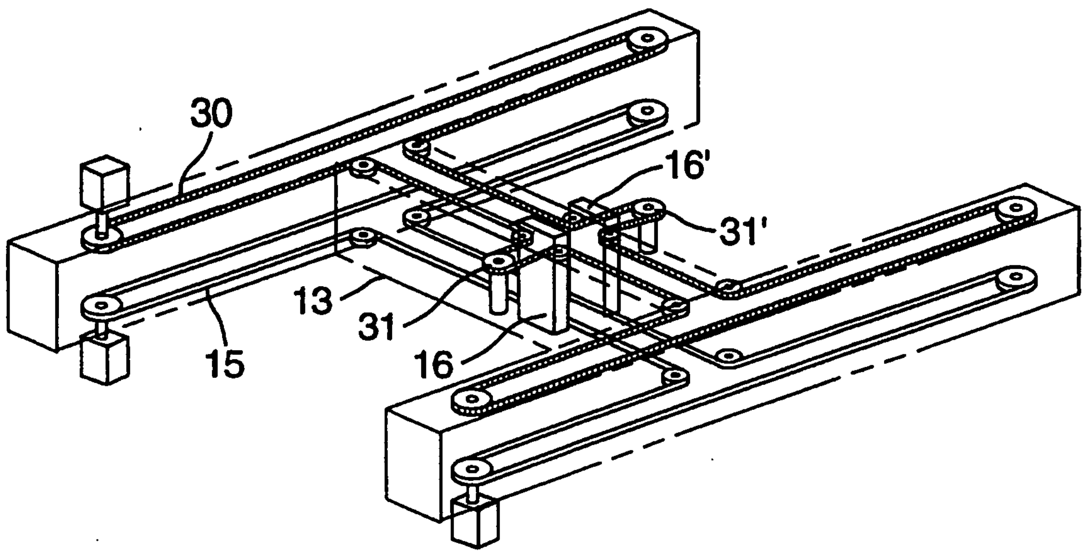

FIG.9

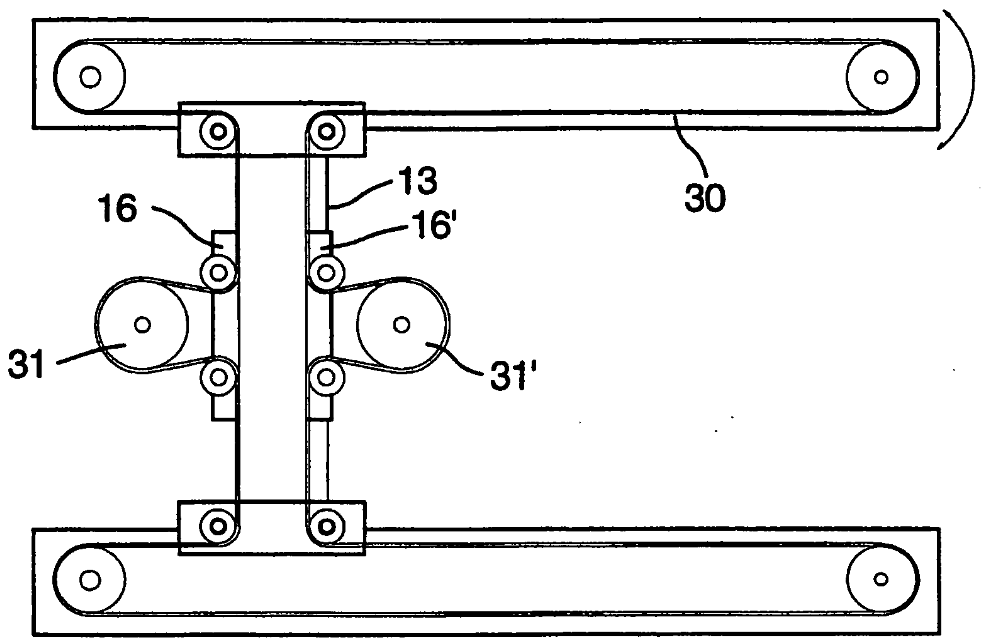

FIG.10

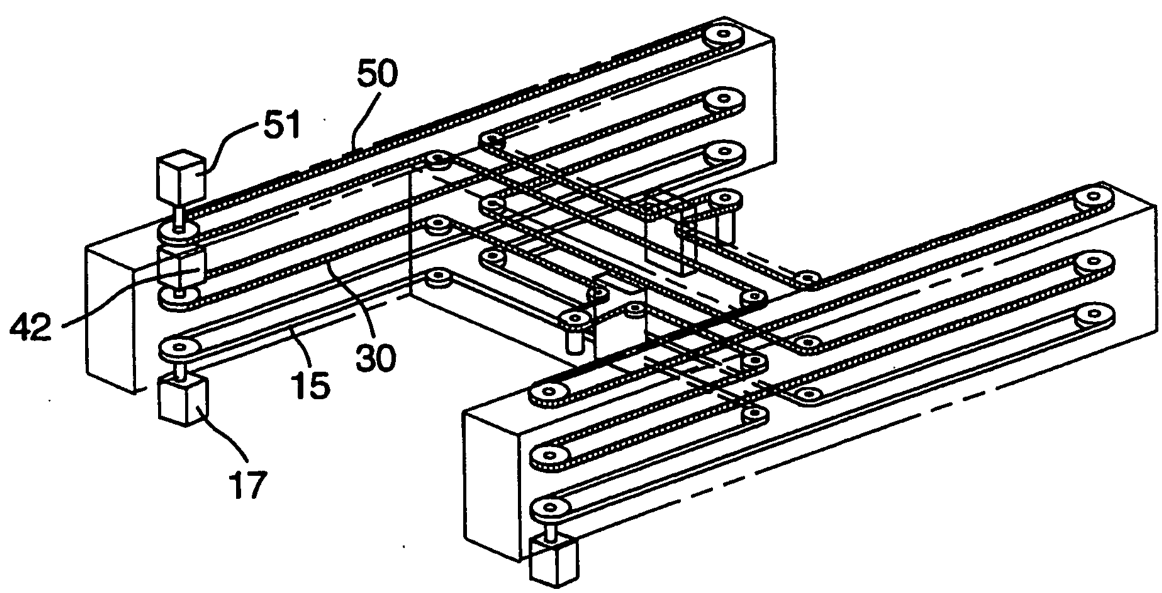

FIG.11

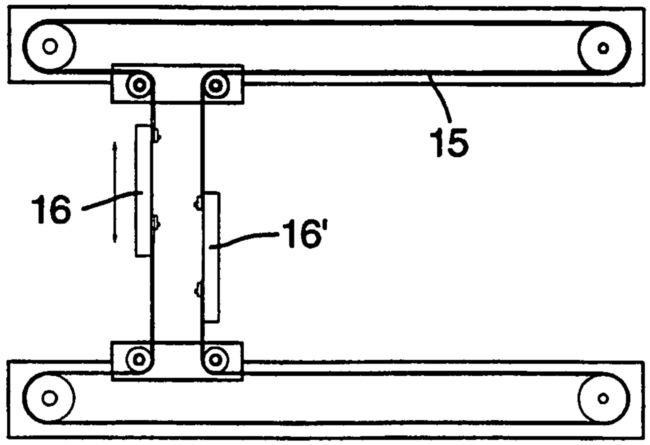

FIG.12

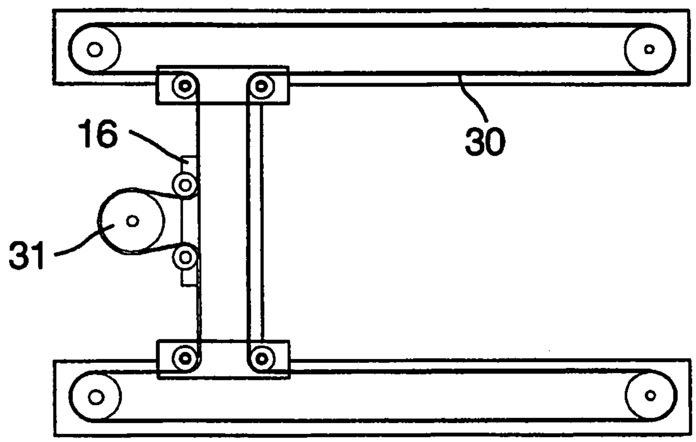

FIG.13

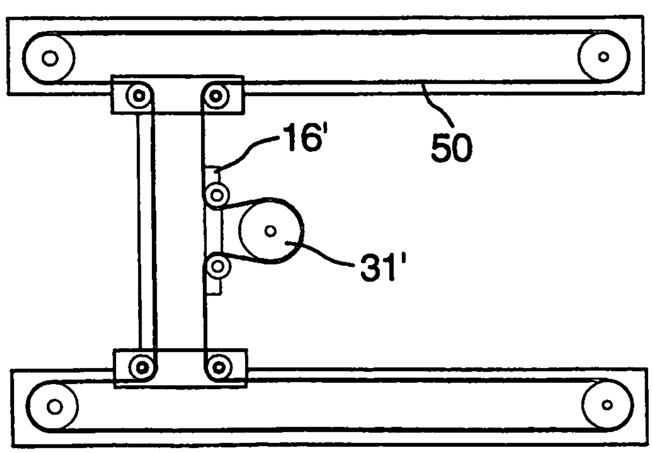

FIG.14

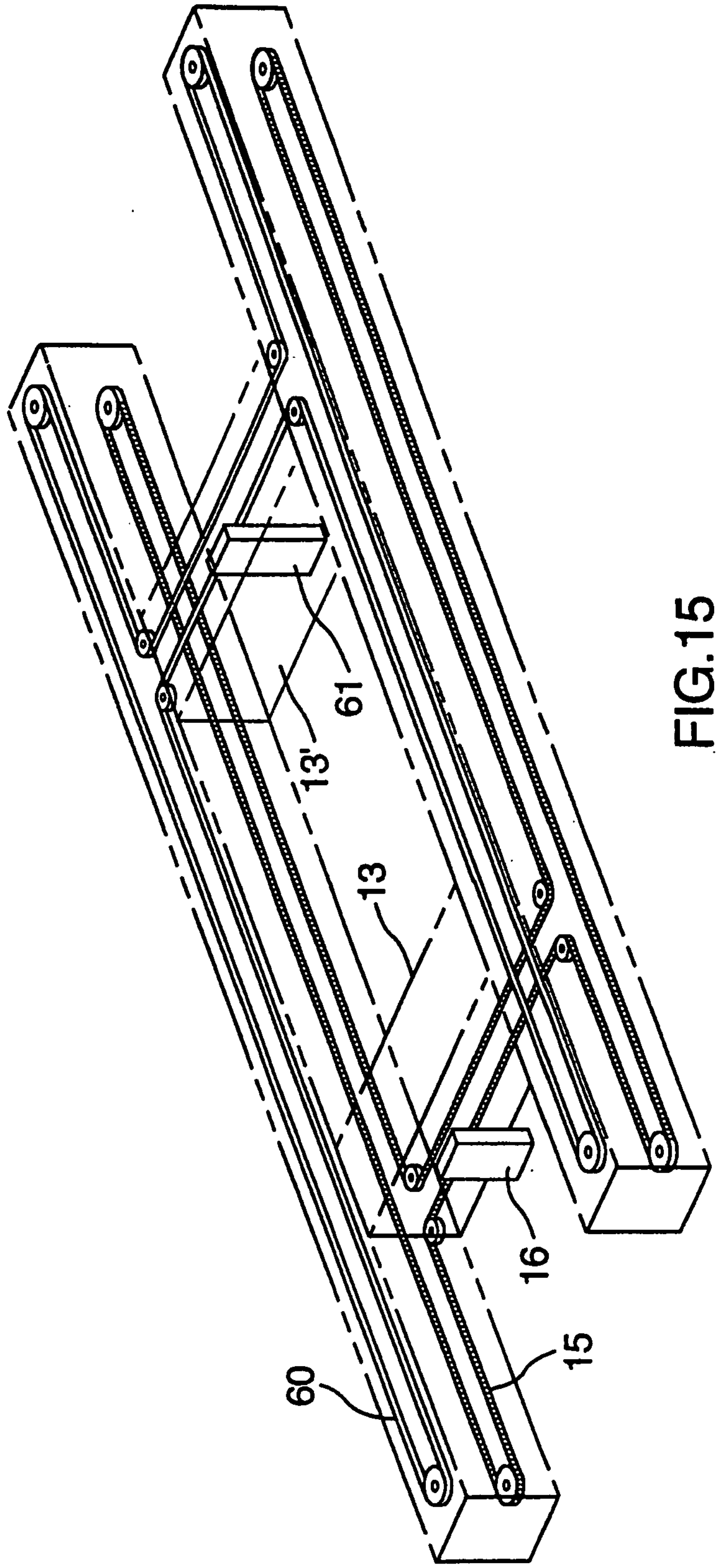

FIG.15

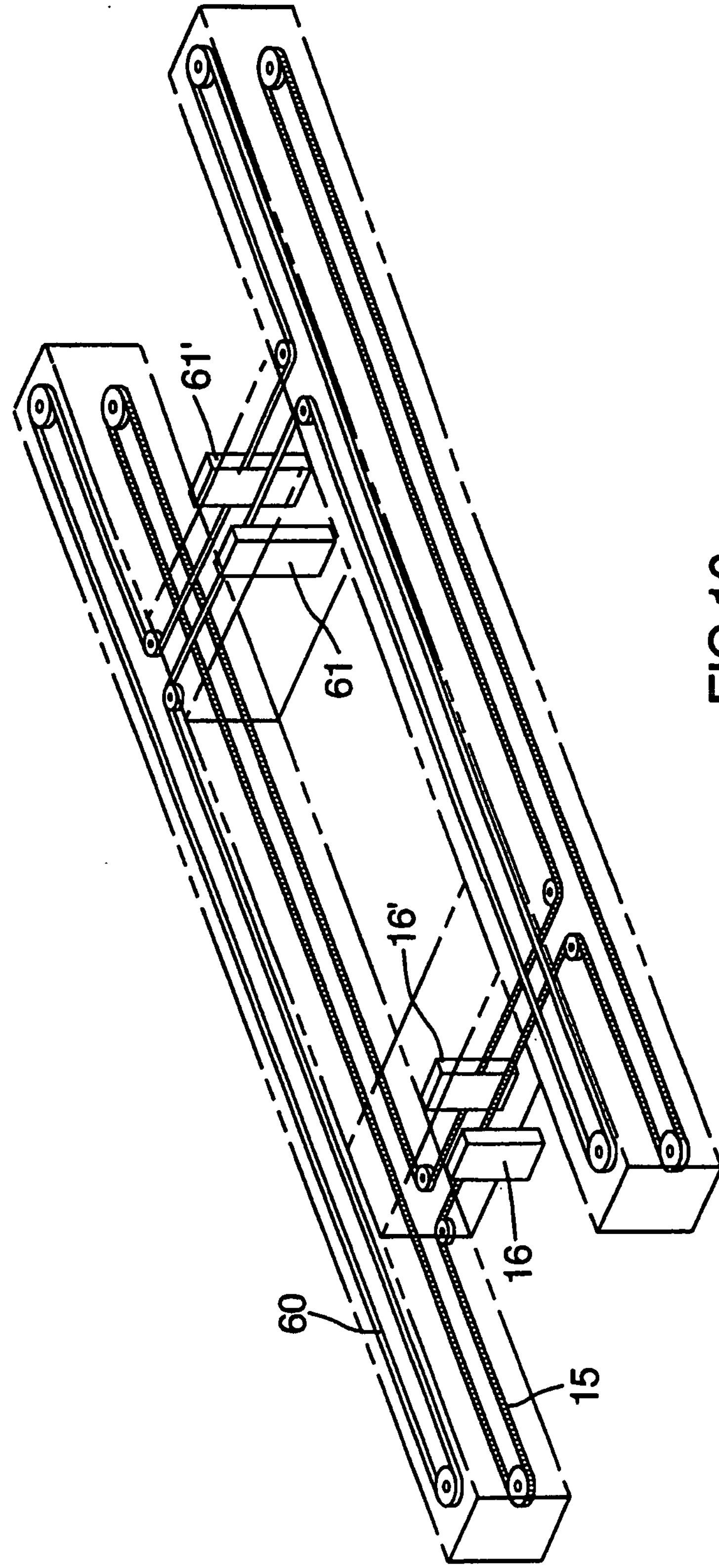

FIG.16

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 96/00450

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B25J9/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR,A,2 676 955 (FAVEYRIAL) 4 December 1992 see page 6, line 8 - page 9, line 28	1,4
Y		5-7

Y	DE,U,88 07 313 (GERHARD BERGER GMBH) 4 August 1988 see claim 1; figures 1,2	5,6

Y	EP,A,0 440 318 (MANNESMANN) 7 August 1991 see column 5, line 51 - column 7, line 36	7

X	FR,A,2 590 560 (GUILBAUD) 29 May 1987 see page 6, line 36 - page 14, line 33	1-3,8

X	EP,A,0 315 310 (THE KEMBLE INSTRUMENT CO. LTD.) 10 May 1989 see column 5, line 44 - column 11, line 23	1-3,8,9

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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1

Date of the actual completion of the international search	Date of mailing of the international search report
7 October 1996	25. 10. 96
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Lammineur, P

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Int 'onal Application No
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1

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